RELATION BETWEEN SUPERPLASTICITY AND PRIOR THERMOMECHANICAL TREATMENT IN LEAD-TIN EUTECTIC

BY

HARISH CHANDRA CHANDAN

DEPARTMENT OF METALLURGICAL ENGINEEING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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HARISH CHANDRA CHANDAN

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DETAILS OF GRADUATE COURSES CREDITED

1. MET 608 Energetics of Physical Systems
2. MET 644 Materials Science I
3. MET 652 Strengthening Mechanisms in Solids
4. MET 640 Solid State Transformations
5. MET 648 Diffusion in Solids
6. MET 652 Deformation Phenomenon I
7. MET 650 Dislocation Theory of Plastic Deformation
8. CHE 682 Nuclear Chemical Processes

GRADUATE SEMINARS CREDITED

1. Shock Hardening
2. Superplasticity
3. The Influence of Lattice Friction on Point Defect Hardening.
4. Very Early Stages in Plastic Deformation.
5. A Statistical Investigation of Microcrack Formation.

This is to certify that Mr. Harish Chandra Chandan has credited above listed courses and seminars.

HCChandan

Signature of the Student

G. S. Murty

(DR. G. S. MURTY)
Assistant Professor
Department of Metallurgical Engineering
Indian Institute of Technology
Kanpur, India

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ABSTRACT

Using the widest terms of reference, Superplastic deformation can be said to be characterised by ductility under small tensile, compressive or torsional forces that is well in excess of conventional behaviour. Several investigations have been done on Superplastic behaviour of Pb-Sn eutectic. Apart from studying the general phenomenon of Superplasticity, observations have been made to delineate the effect of prior mechanical and thermal processing on Superplastic behaviour. As-cast eutectic is lamellar and is not Superplastic. Increasing prior reduction leads to a relatively equiaxed structure which has smooth interphase boundaries. Annealing produced an assymetric structure with zig-zag interphase boundaries. The Superplastic behaviour seems to depend on nature of interphase boundary and shape of second phase particle. An equiaxed shape and smooth interphase boundary leads to better Superplastic properties. Even same grain-sized samples which were processed differently behave differently possibly because of the difference in the shape of second phase particles and nature of interphase boundary. The maximum grain size obtained by severe prior reduction and by annealing upto 7 days was 2.80 microns.

CHAPTER 1

1.1 Introduction

We begin with a brief note on the historical development in this field. In 1920, Rosenhain observed that the cold-rolled Zinc: Copper: Aluminum ternary eutectic alloy 'behaved differently from ordinary crystalline materials, such as Aluminum but very similar to ... Pitch, glass etc'. A few year later Sauveur noted that an Iron bar tested in a temperature gradient exhibits regions of easy twisting at the transformation temperatures. Pearson (1934) found that a fine-grain Bismuth - Tin and Tin-Lead eutectic alloy could be extended upto 2000% in a tension test. Sauerwald (1949) reported that a number of alloys based on Aluminum and Zinc had extremely large tensile elongations. Nearly at the same time Bochvar and Sviderskaia observed the phenomenon of large extensibility, also in Al-Zn alloy. Underwood[17] reported a literature-survey in 1962, which covered nearly all the work done to date. Backofen, Turner and Avery[18] (1964) proposed and proved that Superplasticity results from a high strain-rate sensitivity of the flow stress. Their paper provided a foundation for the recent and continuing research in this field. Various metals, alloys and ceramics have been studied since 1964. Recently (1970) two more reviews[14,19] on the subject have appeared. Padmanabhan et.al[19] have listed all the metals, alloys and ceramics, that have been studied so far, along with corresponding references. A

lot of work has been done on Tin-Lead-eutectic system which is the subject of present investigation also[20-25,1,15]. Sn-2% Pb[15], Sn-81% Pb[15] and Sn[15] have also been studied.

A superplastic material (metal, alloy or a ceramic) flows with the fluid-like character of hot polymers and glasses. In solid crystalline materials this is a relatively rare phenomenon and only in the last six years has it been widely demonstrated. At the present time Superplasticity is most commonly associated with exceptionally large elongations in metals but is not necessarily restricted to such cases and no particular mechanism of deformation is inferred by applying the name 'Superplastic'. Using the widest terms of reference, Superplastic deformation can be said to be characterised by ductility under small tensile, compressive or torsional forces that is well in excess of conventional behaviour.

Superplastic materials can broadly be divided into two groups :

(1) Structural Superplasticity: is exhibited by those materials in which a characteristic structural condition exists, e.g., a stable, ultra-fine grain size of the order of a few microns.

(2) Environmental Superplasticity: is exhibited by those materials for which special testing conditions are necessary, e.g., temperature cycling under a small applied stress. This cycling induces repeated phase transformation as in Iron.

In both groups, it is now generally agreed that the extensive elongation can be correlated with a high strain-rate

sensitivity of flow-stress[26-28,18]. This characteristic is described by a parameter m defined by :

$$m = \frac{\partial \log \sigma}{\partial \log \dot{\epsilon}} \qquad .. \qquad (1)$$

where σ = Applied true stress

$\dot{\epsilon}$ = True strain rate.

In general, the magnitude of m identifies a Superplastic material irrespective of the mode of straining and the origin of Superplastic behaviour. The materials exhibiting Structural Superplasticity have m in the range 0.3 - 0.8, while the materials exhibiting Environmental Superplasticity have $m \cong 1$. In conventional materials m is less than 0.3. In glass, m = 1 and this material exhibits Newtonian-viscous behaviour. Materials which show serrated yielding have negative m.

The superplastic elongation is different from normal elongation. This can be explained as follows. A normal ductile material when stretched by a tensile force can deform uniformly only when stable flow occurs. The flow, at temperatures less than about $T_m/2$ (T_m is melting point of material), is stabilised by strain hardening effects. The limit of stable flow is marked by the onset of geometrical instability or necking which occurs when the material has exhausted its capacity for strain hardening. For further stable extension the material must be unloaded and then annealed, thus restoring the ability to strain-harden again on applying the load. This is the behaviour of normal material. The Superplastic material

deforms differently. It does <u>not</u> strain-harden. In this case, the stable flow is not due to the strain-hardening effect but is due to high strain-rate-sensitivity of flow stress. Mathematically, for a normal ductile material we have, at test temperature $T < T_m/2$,

$$\sigma = C\epsilon^n \qquad .. \qquad (2)$$

where σ = True stress

ϵ = True strain

C = Strength coefficient

n = Strain-hardening-exponent.

The value of n is generally less than 0.3 which means that the stable flow or uniform elongation does not exceed 30% elongation because it can be shown both theoretically and experimentally that

$$\epsilon_{necking} = n$$

At test temperature $T > T_m/2$, the stability of plastic deformation is due to high strain-rate-sensitivity of flow stress. Mathematically,

$$\sigma = K(\dot{\epsilon})^m \qquad .. \qquad (3)$$

where K = constant for given testing conditions and is a material parameter.

$\dot{\epsilon}$ = Strain rate.

The stability of plastic deformation when both strain-hardening and strain-rate effects need to be considered, has been examined by Rossard[39], Hart[28] and Campbell[40]. In such a case,